Developments of Parametric Loudspeaker for Practical Use

KAMAKURA Tomoo*, YONEYAMA Masahide** and IKEGAYA Kazuo*

* Department of Electrical Engineering, Nagoya University
Furo-cho,Chikusa-ku,Nagoya 464,Japan

** Technology Division, Ricoh Company, LTD
1-17,1-chome,Koishikawa,Bunkyo-ku,Tokyo 112,Japan

I. Introduction

Parametric loudspeaker uses the self-demodulation effect of a finite amplitude ultrasound being amplitude-modulated by audio signals,and the consequent special feature of this loudspeaker is its very sharp directivity.[1)]

There are,however,some significant problems to work out in order to develop the loudspeaker for practical use. First problem is how to decide the optimum values of acoustic parameters,such as carrier frequency and sound pressure level of primary wave that make important effects on the generation of parametric signals. Second,harmonic distortions in demodulated audio sound have to be reduced as small as possible. Third,it is necessary to attenuate the large amplitude ultrasound which is dangerous to auditory sense of human being even in farfield region of parametric loudspeaker. Detail investigations of the above problems are made in the following sections.

II. Optimum acoustic parameters

To calculate parametric level,Moffett and Mellen have proposed the model for the source of which primary wave is assumed to be planar out to Rayleigh length and spherically spreading beyond that range.[2)] Under the condition that primary wave consists of two discrete frequency components of equal amplitude P_0,they obtained the treatable equation for calculations of parametric gain.

Figure 1 shows a calculated result using the Moffett and Mellen's equation. Here,effective radius of a sound source and secondary frequency are assumed to be 15cm and 3kHz,respectively. Abscissa in the figure denotes the primary sound pressure P_0 and ordinate the source level of secondary wave. Center frequency of two primary components,the most important parameter to be reasonably decided for designing of a parametric loudspeaker is taken from 10kHz to 100kHz.

As can be seen in Fig.1, the lower the primary frequency becomes,the higher the parametric level increases. However,the primary wave of low frequency broadens secondary wave beam patterns and it is difficult to radiate low frequency finite amplitude waves. Hence,it would be appropriate to choose the primary frequency in the range of 30kHz to 70kHz.

III. Distortion reduction

Now let an amplitude-modulated ultrasound

$$Pi = P_0 \cdot f(t) \cdot \sin \omega_0 t \qquad (1)$$

be radiated in freefield. Where, $f(t)$ is the envelope function of varing much slowly than the carrier signal $\sin\omega_0 t$. If the ultrasound beam is collimated and receiving point is located in far region and on the acoustic axis of the loudspeaker, then parametric signal $p(t)$ is proportional to the 2nd time derivative of $f^2(t)$; that is,

$$p(t) \propto \frac{\partial^2}{\partial t^2} f^2\left(t - \frac{r}{c}\right) \qquad (2)$$

as far as quasilinear approach for nonlinear acoustic field holds. So, when $f(t)$ takes the linear relation to audio signal $s(t)$ as

$$f(t) = 1 + m \cdot s(t) \qquad (3)$$

p becomes

$$p(t) \propto \frac{\partial^2}{\partial t^2} \left\{ 2 \cdot m \cdot s\left(t - \frac{r}{c}\right) + m^2 \cdot s^2\left(t - \frac{r}{c}\right) \right\} \qquad (4)$$

where m denotes modulation index. This DSB excitation, therefore, generates harmonic distortion component $m^2 s^2$, of which magnitude increases with modulation index. To avoid the above mentioned distortion, we propose a new type modulation of primary wave as the following form,

$$f(t) = \sqrt{1 + m \cdot s(t)} \qquad (5)$$

Using the pre-distorted envelope function in this way, the desired audio sound may be obtained. In general, the bandwidth of the modified DSB excitation given as eq.(5) widens than that of usual DSB excitation. Hence, transducers which compose of the loudspeaker require wideband frequency response characteristics.

Experimental verifications for the distortion reduction by means of MDSB excitation were made. The parametric loudspeaker consists of 581 PZT bimorph transducers of 40kHz resonance frequency and is photographed in Fig.2.

Figure 3 shows the 2nd and 3rd harmonic components of demodulated sound. Input

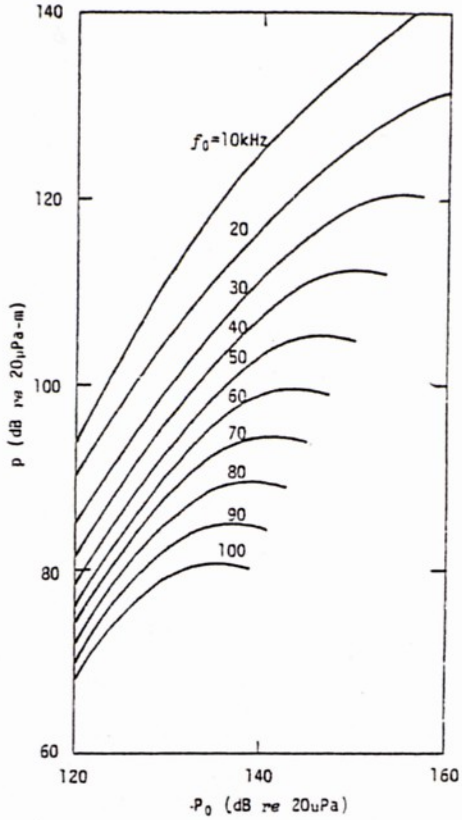

Fig.1 Calculated curves of secondary wave sound pressure. f_0 ; center frequency of primary wave. secondary frequency = 3kHz.

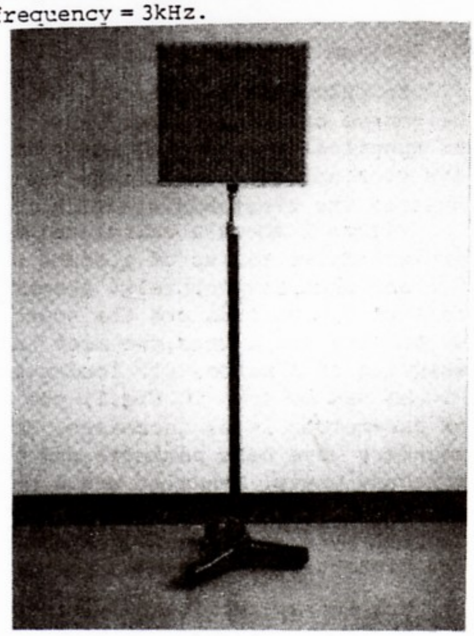

Fig.2 View of the parametric loudspeaker

signals to the loudspeaker are sinusoidal waves of 1kHz to 2.5kHz. Each modulation index for both excitations is unity;that is,m=1.

The experimental results verify that MDSB excitation generates less harmonic distortion than DSB excitation as a whole. In particular, 2nd harmonic distortion is reduced about 10dB, however,3rd harmonic components are relatively large and increase with frequency. Anyhow, theoretically nonexistent harmonic components are really generated. This is probably due to the fact that the frequency response of transducer is not so wide as we expect.

The on-axis SPLs of parametric signal at the point of 9.5m were measured under the condition that peak values of applied voltage to the loudspeaker are equal for DSB and MDSB excitations,and the results are shown in Fig.4. The amplitudes of demodulated sound pressure are nearly equal for both the excitations.

IV. Acoustic filtering

Even in far region of a parametric loudspeaker SPL of primary wave is generally not low. For example,at 10m from the loudspeaker about 110dB ultrasound propagates through. The ultrasounds in the far region are not only of no use for parametric signal production but also are dangerous for auditory sense of human being. So,it is important to attenuate unuseful ultrasounds without decreasing parametric levels. For the aim,the most beneficial procedure is to use an appropriate acoustic filter. Figure 5 shows the sound transmission losses of primary and secondary waves by inserting an acoustic material,a sheet of air-pad across the propagation pass of ultrasound. Here,we define the transmission loss by the ratio of sound pressures without the sheet to with it. Microphone was located at the point of 8.5m and the sheet of the size 1.2m x 1.5m was inserted at five points from 1.5m to 8m. The distance between loudspeaker and microphone is slightly longer than array length and shorter than Rayleigh length. It should be noted that air-pad material is one of the appropriate acoustic filters that attenuate 40kHz ultrasound more than 20dB.

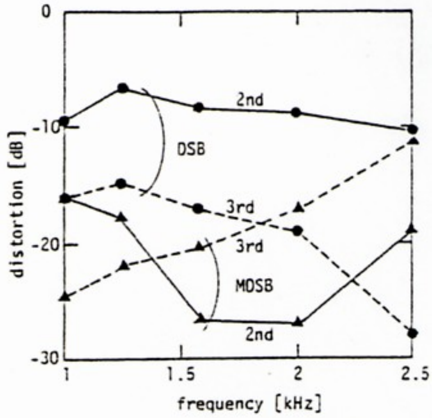

Fig.3 2nd and 3rd harmonic components of demodulated sound

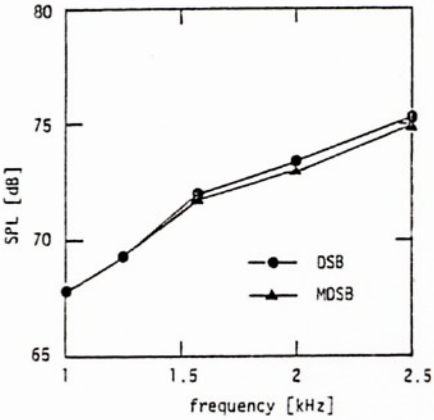

Fig.4 SPLs of secondary wave. Peak values of applied voltage to the loudspeaker are equal for DBS and MDSB excitations. distance = 9.5 m

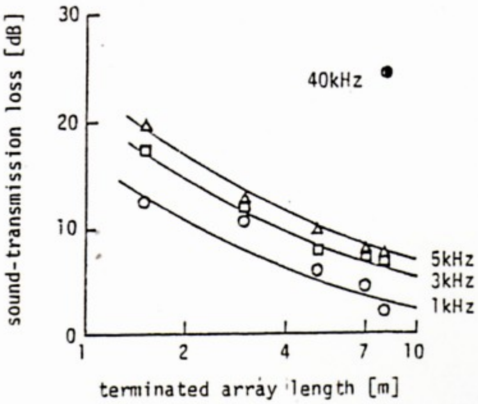

Fig.5 Sound transmission losses of primary and secondary waves by inserting a sheet of air-pad.

V. Remarks

A parametric loudspeaker has very sharp directivity,but can not generate large amplitude audio sounds. If high levels of the sounds are required,it would be an effective way to construct the audio spot-light system of using several parametric loudspeakers.

References

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2) M.B.Moffett and R.H.Mellen,"Model for parametric acoustic sources,"J.Acoust. Soc.Am.61,325-337(1977)